Army Research Laboratory

Corrosion Immersion Testing of 13-mm-Diameter Grade-10.9 Bolts for Bolt-on Armor

by Tom Considine and Tom Braswell

ARL-CR-654 July 2010

prepared by

Oak Ridge Institute for Science and Education
4692 Millennium Dr., Ste. 101
Belcamp, MD 21017

and

Versar
6850 Versar Center
Springfield, VA 22151

under contract

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NOTICES

Disclaimers

Army Research Laboratory

Aberdeen Proving Ground, MD 21005-5069

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14. ABSTRACT
This experiment examined the performance of selected coatings and pretreatments on 13-mm grade-10.9 bolts immersed in a 5% NaCl solution in an attempt to evaluate the corrosion prevention properties of each selected coating and pretreatment relevant to those selected for bolt-on armor. Five candidate finishes as well as zinc plating in accordance with ASTM B 633 with hexavalent chromium conversion coating as control were tested. Each bath was heated to 75 °F, and the salt solution was agitated in order to prevent stagnation and ensure equal heating. Testing was completed over 500 h, with visual inspections and open circuit potential measurements at 1, 2, 4, 8, and 24 h, and once every 24 h following. In this experiment, corrosion creep was defined visually as frosting for the onset of corrosion and red rust in the percentage of the fastener affected, each yielding separate observations.

15. SUBJECT TERMS
bolt, armor, chromium, hexavalent, TCP, AlumiPlate, MagniPlate, immersion

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1. Introduction

Finding a replacement for hexavalent chromium-based finishes for fasteners was the driver for this experiment. The purpose of this experiment was to quantify the corrosion-inhibiting performance of the selected coatings for the 13-mm bolts and to determine the possible preferred selection for the customer. Immersion corrosion testing was chosen for this experiment because of its acceleration of corrosion to quickly showcase weaknesses, and it is the second phase of testing done with respect to the candidates for bolt-on armor. Experimental procedures for this evaluation were basic and did not include the wear and tear that fasteners typically would receive during processing storage, assembly, and use.

2. Methods and Materials

1. Grant W-38 Thermostatic Circulated Bath (calibrated)
2. 5% NaCl solution
3. Four thermometers (calibrated)
4. Fluke 289 True RMS multimeter

3. Test Candidates

The test candidates consisted of grade-10.9 13-mm hexavalent bolts, nuts, and washers.

1. Bare 4340 steel.
2. Control: ASTM B 633 electroplated zinc with hexavalent chromium conversion coating.
3. Trivalent chrome plating (TCP): ASTM B 633 electroplated zinc with trivalent chromium conversion coating.
4. AlumiPlate (AlumiPlate, Inc.) process details: Entire surface was electroplated with Al alloy 1199 at 99.99% pure and conversion coated with Metalast TCP, then the threaded areas were coated in accordance with MIL-PRF-46010 solid film lubricant (Everlube 9002).

5. Magni 565 (MagniGroup, Inc.) process details: Entire surface was coated with inorganic, zinc-rich coating, and topcoated with an Al-rich organic topcoat.
6. Magni 594 (MagniGroup, Inc.) process details: Entire surface was coated with inorganic zinc coating and topcoated with a friction-modified, organic Al-rich coating.

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4. Experimental Procedure

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1. Each bolt had a 1/8-in hole bored into the center of its head (see figure 1).
2. A Zn-plated steel screw, wrapped with wire, was fixed in place using this hole.
3. Polysulfide sealant was used to insulate and seal the wire/screw assembly to the bolt to prevent contamination (see figure 2 for full assembly).
4. A thermostatic circulated bath was filled with a 5% NaCl solution and heated to 75 °F. Solution temperature was maintained for the duration of the experiment, and the water was continually agitated.
5. Two of each specimen were immersed in the bath for 500 h. Open circuit potential measurements and visual inspections were taken after 1, 2, 4, 8, and 24 h, and every 24 h thereafter.

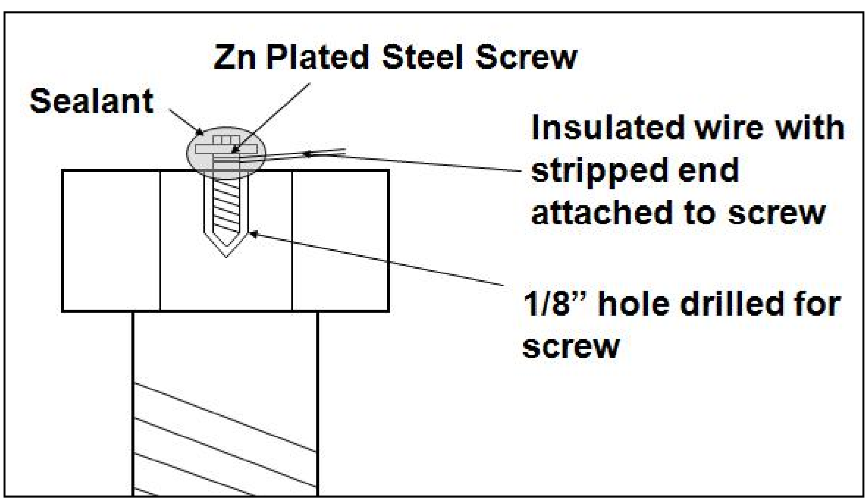

Figure 1. Bolt/screw assembly.

(a) (b)

Figure 2. (a) Prepared bolts prior to immersion and (b) immersion bath setup.

5. Results and Discussion

With respect to cosmetic corrosion, the TCP/zinc-treated bolts corroded at a faster rate than bare steel. Bare steel and TCP/zinc were the only two bolt types that corroded faster than hexavalent chrome/zinc, as AlumiPlate and both types of MagniPlate experienced significantly less corrosion (figure 3). After the 500-h immersion, only the bare steel and TCP/zinc bolts ever reached 100% surface area corrosion. The open circuit potential of each bolt was also measured and recorded throughout the course of the immersion experiment. As can be seen in figure 4, the bare steel provided a baseline of about 0.68 V. With the exception of MagniPlate 594, all the treated bolt specimens made it to 120 h without a significant change in open circuit potential. MagniPlate 594 immediately dropped in voltage and eventually ended up at the same potential as that of bare steel. AlumiPlate and MagniPlate 565 both experienced drops in potential after 120 h, though not nearly as severe as that of MagniPlate 594, and finished out the immersion period at 0.7755 and 0.8498 V, respectively. Despite the appearance of immediate cosmetic corrosion, TCP/zinc did not show signs of any change in potential until after 250 h of immersion. At this point, the drop-off in potential dropped drastically and never leveled out prior to the end of the experiment. Photos of the bolts after being removed from the solution can be seen in figures 5–10, while scans of the dried bolts can be seen in figures 11 and 12. Although the open circuit potential of the hexavalent chrome/zinc bolts remained high throughout the experiment, the bolts appeared to have lost their protective coating and showed a significant amount of steel corrosion.

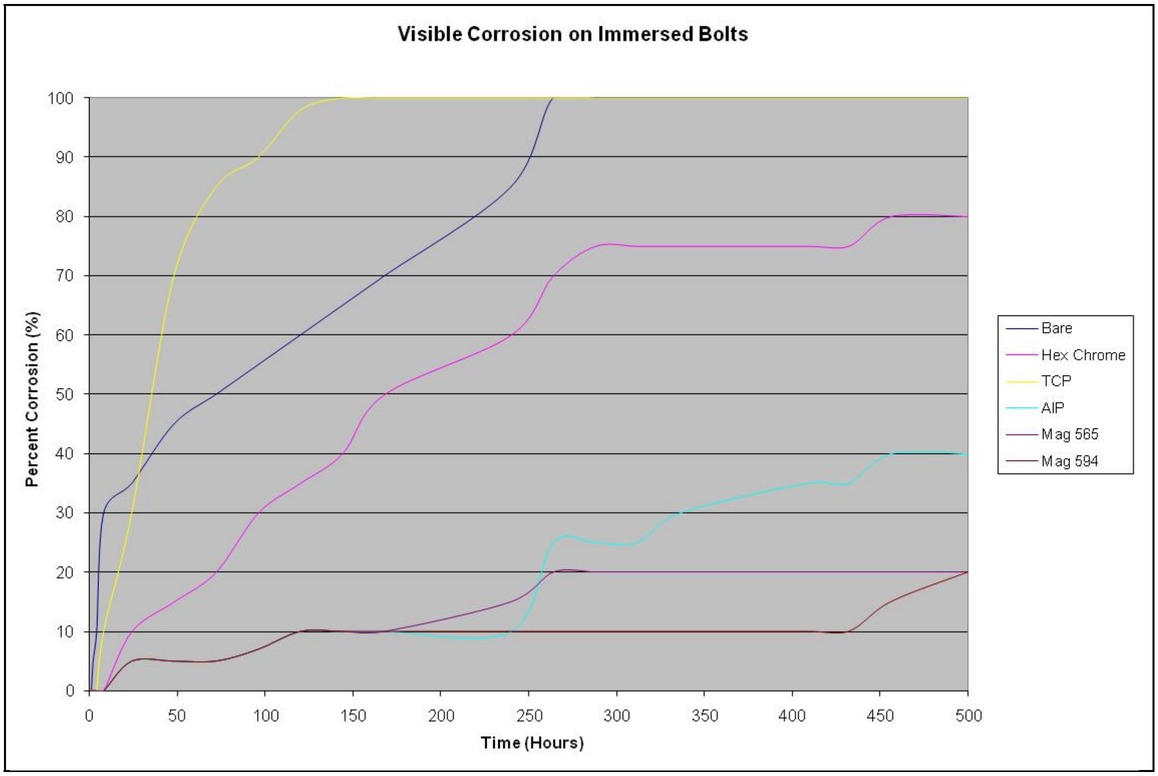

Figure 3. Visual corrosion on immersed bolts.

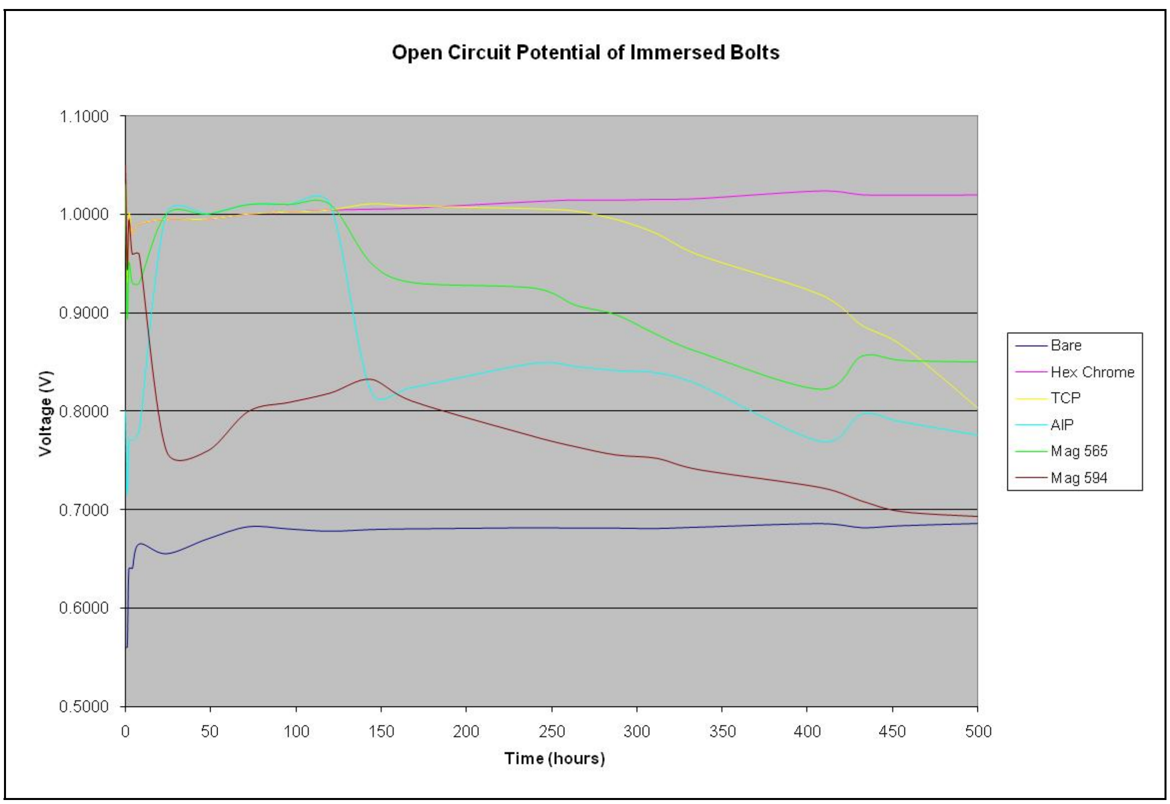

Figure 4. Open circuit potential of immersed bolts.

Figure 5. Bare bolts immediately after immersion.

Figure 6. Hexavalent chrome/zinc bolts immediately after immersion.

Figure 7. TCP/zinc bolts immediately after immersion.

Figure 8. AlumiPlate bolts immediately after immersion.

Figure 9. MagniPlate 565 immediately after immersion.

Figure 10. MagniPlate 594 immediately after immersion.

Figure 11. Bare steel, hexavalent chrome/zinc, and TCP/zinc after drying.

Figure 12. AlumiPlate, MagniPlate 565, and MagniPlate 594 after drying.

With respect given to the original experimental setup and aided by a wealth of extra bolts, it was decided by a team of engineers to try the experiment a second time. This second experiment would be set up just as the first but with each bolt type isolated from each other so as to prevent cross-contamination. Pyrex glass jars were filled with a 5% salt solution and fitted with an agitation system using clean, dry air to circulate the water. The glass jars sat in the same water bath and were heated to 75 °F for 500 h. The results of this supplementary experiment are shown in figures 13–22. Unlike the original setup, the hexavalent chrome/zinc bolts did not show any signs of coating loss or steel corrosion. Visible corrosion was also different in that the TCP and bare 4340 bolts corroded quickly and heavily, whereas the other bolts experienced much less corrosion, none of which ever exceeded 10%. The open circuit potential readings were not as stable as before, as all bolt specimens tested experienced a drop-off after 250 h.

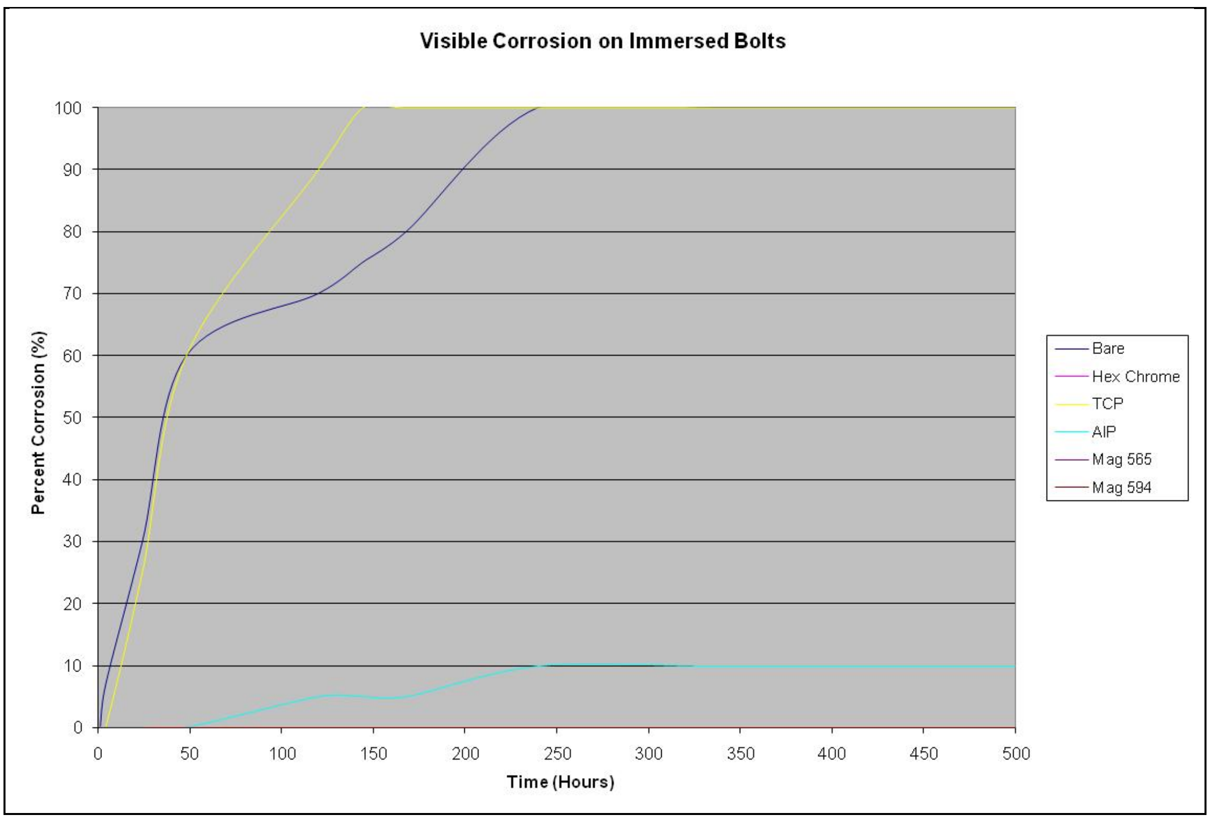

Figure 13. Visual corrosion on immersed bolts in supplementary experiment.

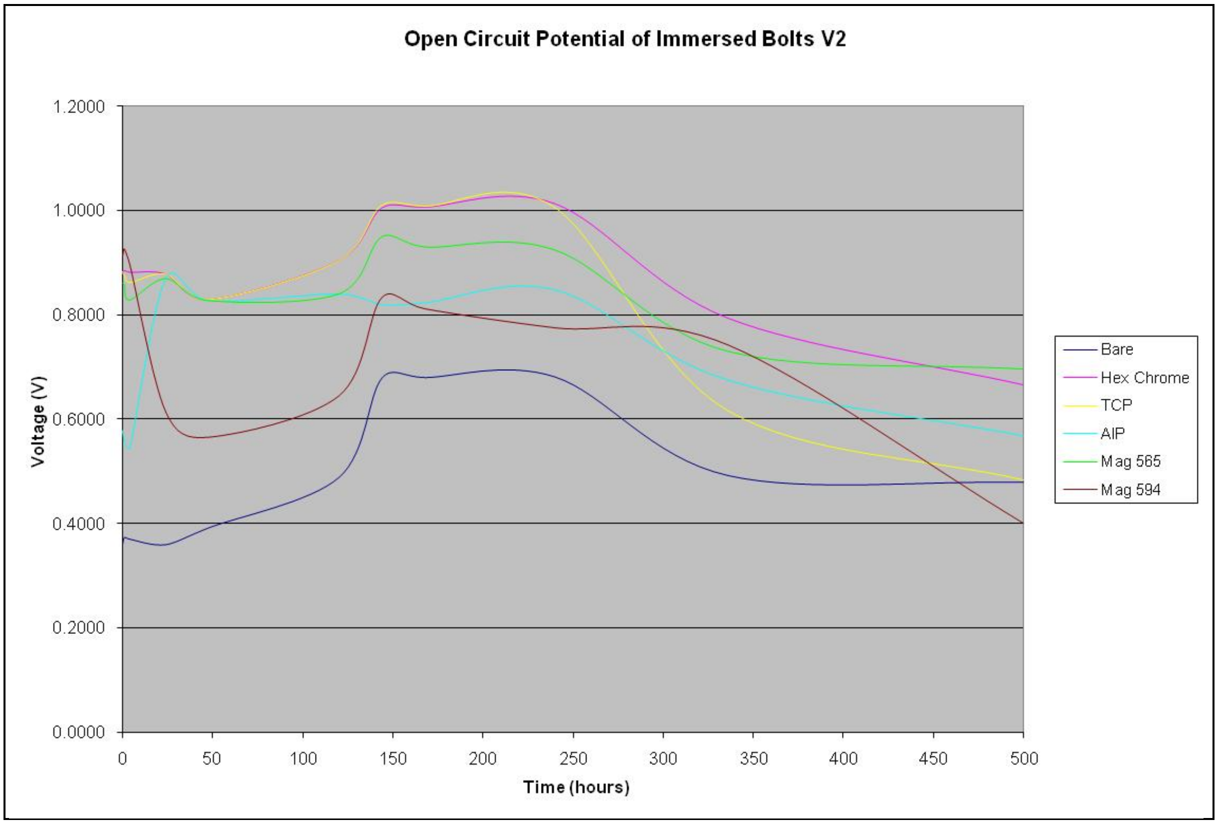

Figure 14. Open circuit potential of immersed bolts in supplementary experiment.

Figure 15. Bare bolts immediately after immersion in supplementary experiment.

Figure 16. Hexavalent chrome/zinc bolts immediately after immersion in supplementary experiment.

Figure 17. TCP/zinc bolts immediately after immersion in supplementary experiment.

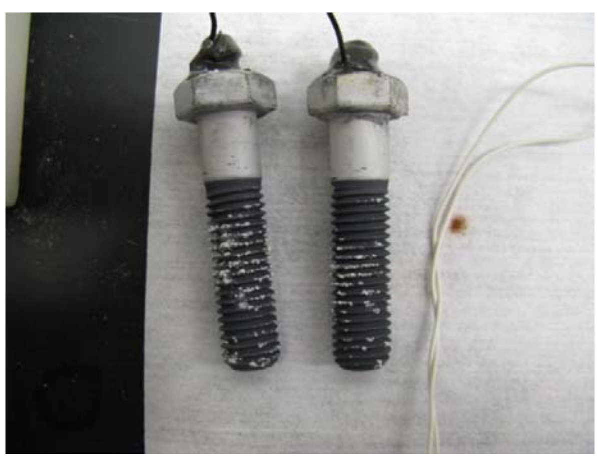

Figure 18. AlumiPlate bolts immediately after immersion in supplementary experiment.

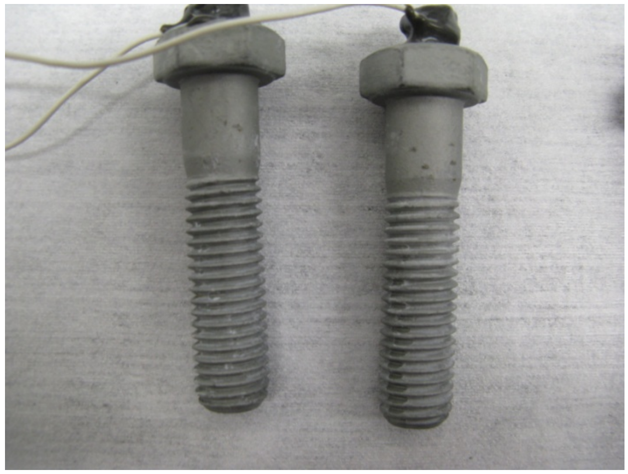

Figure 19. MagniPlate 565 immediately after immersion in supplementary experiment.

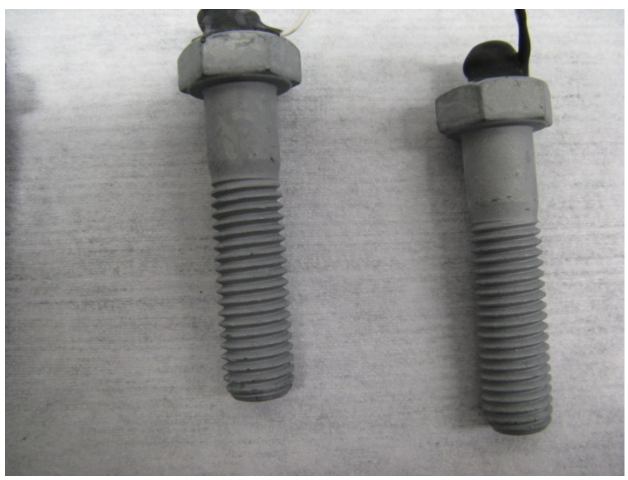

Figure 20. MagniPlate 594 immediately after immersion in supplementary experiment.

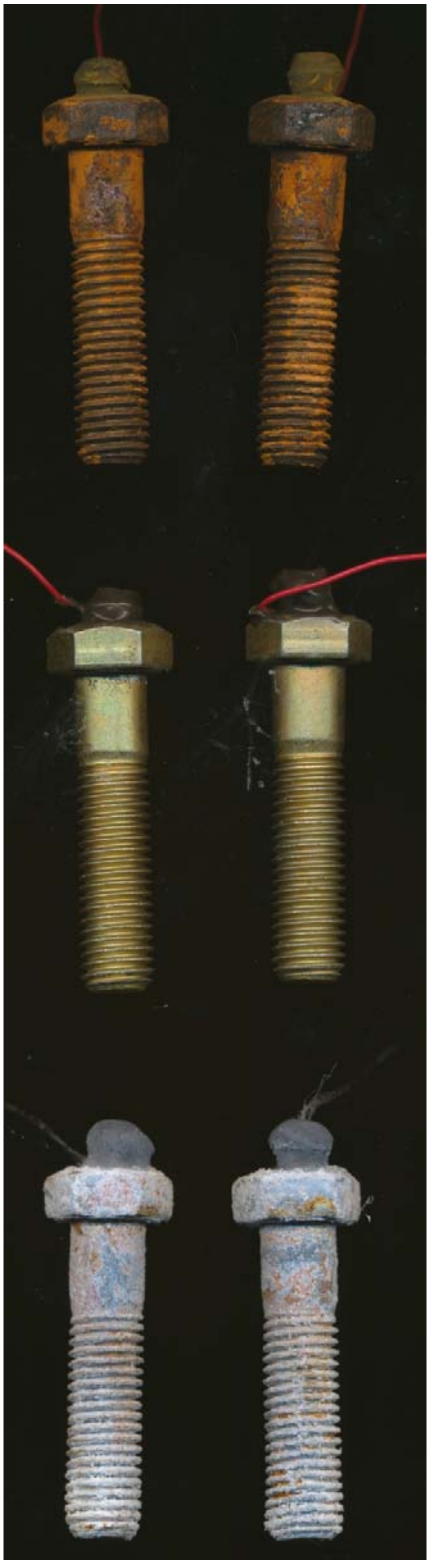

Figure 21. Bare steel, hexavalent chrome/zinc, and TCP/zinc after drying in supplementary experiment.

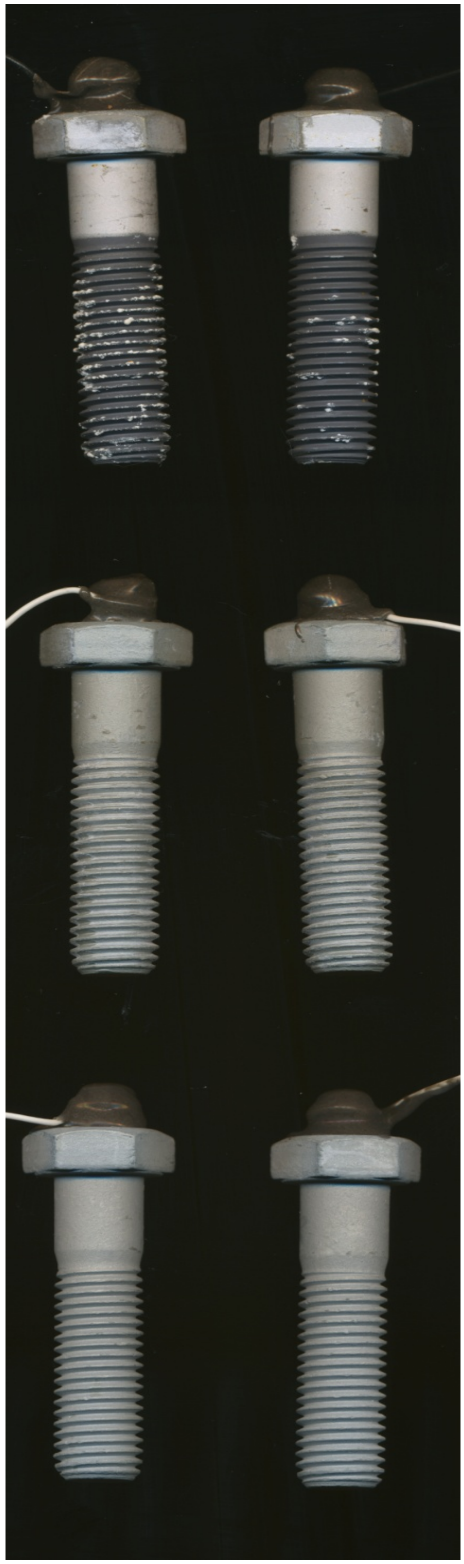

Figure 22. AlumiPlate, MagniPlate 565, and MagniPlate 594 after drying in supplementary experiment.

6. Conclusions

- MagniPlate 565 and 594 had the least visible corrosion.
- MagniPlate 565 and 594, and AlumiPlate experienced less corrosion than the baseline hexavalent chrome/zinc.
- Aside from hexavalent chrome/zinc, which maintained essentially the same open circuit potential throughout the experiment, MagniPlate 565 maintained the second-highest potential with respect to the baseline given by the bare steel bolts.
- The TCP/zinc used should be given further analysis in order to explain its poor performance.
- Additional studies should be done to examine the compatibility of MagniPlate 565 and 594, and AlumiPlate with existing armor systems.

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